was the recipient of the highest honors that Europe has to bestow, to an extent scarcely vouchsafed to any other American. A few only will be named here: Mem. Roy. Soc. (London); For. Assoc. Roy. Astr. Soc. (London); Cor. Mem. Acad. Sci. (Institut de France); Acad. Imp. Sci. (St. Petersburg); Kön. Akad. Wiss. (Berlin); Kön. Ges. Wiss. (Göttingen); Kais. Akad. Wiss. (Vienna); Bur. d. Long. (Paris). He was also knighted, of the Order Pour le Merite, by the German Empire, a distinction never given to any other American and exceedingly rare even in Europe.

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THE INFLUENCE OF LIGHT ON THE DISCHARGE OF ELECTRIFIED BODIES. II.

CONNECTION BETWEEN PHOTO-ELECTRIC SENSITIVENESS AND ABSORBING POWER. WORK OF STOLETOW, HALLWACHS, ETC.

58. THE fact that water is an inactive substance as regards the negative discharge was shown by Bichat and Blondlot* by means of an apparatus similar to that used by Righi. Instead of a metal plate a sheet of glass was used, over which a stream of water was allowed to flow. In front of this was placed a wire gauze. It was impossible to obtain any current between water and gauze by illumination, even when 80 cells were used. The authors point out that water is transparent to the effective rays, as first shown by Hertz.

59. Stoletow† used a method similar to that of Bichat and Blondlot with various colored liquids, such as solutions of Fuchsin, Eosin and Fluorescin in ammonia. He came to the conclusion that the effect was always greatest in those liquids which were *capable of absorbing the active rays*.

60. This conclusion was in the main confirmed by Hallwachs* by more reliable and systematic methods. The liquids to be tested were placed in a rather large watch glass, and were illuminated by an arc light placed vertically above the surface. A screen of quartz or gypsum was placed beneath the lamp to prevent disturbance from carbon particles. Connection was made between the liquid and the electrometer by a platinum wire, and the effect of illumination was measured by the rate of dissipation a negative charge on the liquid surface. Some of the results are given below:

Aqueous solutions of Fuchsin, Cyanin	as sensitive as metals
Aqueous solutions of KNO_3, Eosin, Haematoxylin, Aniline	less sensitive
Water; Solutions of Chromic acid, Potassium permanganate, $Co(NO_3)_2$, KNO_3, KBr; Acetone, Amylacetate	no effect

61. Some trouble was experienced on account of the irregularity of the arc lamp. In order to be able to obtain at any time a measure of its intensity, a piece of copper, which had been oxydized by being brought to a red heat, was kept at a fixed distance from the arc, and the rate of negative discharge from its surface measured from time to time. Such a surface is much less sensitive than one that is polished and clean, but it appears also to be more permanent.

62. Hallwachs gives one series of observations showing the influence of the concentration of the solution. It appears that the intensity of the effect increases less rapidly than the concentration.

63. A consideration of the results showed that all the liquids which were sensitive to the influence possessed a strong absorbing power for ultra-violet rays. The connection between absorption and sensitiveness for the effect does not, however, appear to be a

* C. R. 106, p. 1349. Beibl. 12, 605.

† C. R. 106, p. 1593. Beibl. 12, 723.

* Wied. Ann. 37, p. 666.

simple one. An aqueous solution of fuchsin, for example, is very senitive to the action of the ultra-violet rays; but an alcoholic solution of the same concentration is entirely inactive. Yet the same rays are absorbed by the two solutions, the absorption being more marked with the alcoholic solution. A cell containing the latter, when placed in the path of the rays, destroyed all action on the aqueous solution. The author suggests that the case is analogous to such as occur with fluorescent substances, where the solvent has great influence upon the intensity of the fluorescence.

64. Hallwachs next made an attempt to investigate the effect of different wave-lengths in the neighborhood of ultra-violet absorption bands. A solution of fuchsin showed a strong band between $\lambda = .250\,\mu$ and $\lambda = .275\,\mu$. The solution was tested in a spectrum formed with a quartz prism. But the effect was so weak as to make reliable results impossible.

An approximation to monochromatic rays was obtained by using suitable absorbing media. But it then appeared that the most active rays were in the *extreme* ultra-violet, beyond the absorption bands. The effect in the neighborhood of the bands was too small to enable any conclusion to be drawn.

65. During his experiments Hallwachs found that some of the less active liquids showed some slight effect when *positively* charged. He was inclined to believe, however, that this effect was accidental, and due to the discharge of the induced *negative* electricity on neighboring bodies.

LATER WORK OF WIEDEMANN AND EBERT.

66. At about this time further investigations were undertaken by Wiedemann and Ebert* upon the spark discharge as influenced by ultra-violet rays. The method was practically the same as that first used by these writers.*

* Wied. Ann. 35, p. 209. Before Hallwachs and Lenard and Wolf.

* Wied. Ann. 33, p. 211. See §§ 11–16.

Various metals were first investigated. The electrodes were made of the same form in each case, and great care was shown in obtaining the same intensity and quality of illumination. It was found that Pt was by far the most sensitive of all the metals tried. A telephone, placed in series with the spark gap, showed an especially noticeable change in the character and pitch of the sound when a spark gap of about 2 to 3 mm. was illuminated. The effect in other metals is very much less intense.

In the order of decreasing sensitiveness, the metals are as follows: Zn, Cu, Fe, Al, Pd, Ag.

67. The sparking distance most favorable for showing the effect was found to be different with different metals. The change in the appearance of the spark, under the influence of ultra-violet rays, is discussed in Wiedemann and Ebert's paper at some length (p. 213 l. c.).

68. Experiments with liquids showed that strongly absorbing solutions were most active. The most sensitive liquid was found to be a solution of Nigrosin. Water showed only a very slight effect, which, however, was greatly increased by impurities.

69. At low pressures the effect of illumination was practically *nil*. (But a *slight* reduction of pressure increases the effect. See Hertz, and Wiedemann and Ebert 1st paper.) "As soon as the pressure conditions are such as to cause a considerable development of cathode rays, the influence of illumination can no longer be noticed" (p. 217).

70. Wiedemann & Ebert call attention to the fact that, since their experiments were made upon disruptive discharges, some caution must be used in applying these results to cases of continuous discharge, such as those investigated by Hall-

wachs, Righi, etc. The difference in the nature of the discharge may be a sufficient explanation of apparent contradictions.

71. In discussing the various observations upon the phenomenon in question, E. Wiedemann * is inclined to favor the view that the effect is due to the absorption of ultra-violet rays. He points out that the absorption of rays by resonance brings the absorbing molecules temporarily into the same condition of vibration which they would have if heated sufficiently to send out the same kind of rays as those absorbed, *e. g.*, fluorescence. The rapid and violent vibrations produced in the surface layers of a body by ultra-violet absorption will produce by collisions increased velocity of translation among the molecules, *i. e.*, a rise of temperature. Although the actual temperature rise will be small, yet individual molecules may receive very high velocities, and, being close to the surface, may escape. Convection discharge will therefore be accelerated by the action of ultra-violet light. Note that this explanation fails to give any reason for the selective discharge of negative electricity, unless there is some reason why the particles take on a negative charge by preference. It also fails to explain the fact that the action of ultra-violet rays is much more intense when CO_2 is used instead of air. †

PHOTO-ELECTRIC EFFECT OF SUNLIGHT. BEHAVIOR OF SODIUM AND POTASSIUM.

72. It will be remembered that all of the early observers failed to detect any action produced by sunlight, either on the spark discharge or upon the continuous dissipation of negative electricity. In 1889, however, Hoor claims to have detected some slight effect.* During the same year Nodon† found that insulated conductors of carbon or metal became positively charged when illuminated by sunlight. And almost simultaneous with Nodon, Elster and Geitel ‡ observed both the discharge of negative electricity and the development of a positive charge. A freshly polished zinc plate was found to acquire a positive potential of 2.5 volts. Even diffused daylight produced a measurable effect. Mg and Al were found to be more sensitive than Zn.

73. Based upon this action of sunlight upon the atmosphere and the surface of the earth, Arrhenius § developed in the same year an interesting theory to explain atmospheric electricity, the aurora, etc.

74. The first article of Elster and Geitel is merely a brief note, hurriedly published, probably in order to secure priority. Two months later a full description of their experiments appear in the Annalen.|| The first results were obtained with zinc. A shallow dish 20 cm. in diameter was set up (insulated) in the open air, and was connected with a sensitive electrometer in an adjacent building. The dish was surrounded by a metal case, the top of which could be removed by means of a cord running into the laboratory. Above the sur-

* Wied. Ann. 35, p. 257.

† Wiedemann and Ebert. Wied. Ann. 33, p. 240. This result, first obtained for spark discharges, was found to be also true in the case of a continuous discharge. See Stoletow, C. R. 107, p. 91. Beibl. 12, 723. Observations by Breisig, in which zinc was used as the metal and a lamp flame as the source of illumination, fail to confirm Stoletow's observations. [See Beibl. 17, 60, 1891.] But on the other hand, Breisig's results are contradicted by Cantor. [Beibl. 19, 583.]

* Exner's Repertorium, 25, p. 91; Beibl. 13, 731. Righi, however, (Exner's Repertorium 25, p. 380. Beibl. 14, 68) contradicts the results of Hoor, and states that he has 'never succeeded in obtaining the slightest trace of an effect from sunlight.' Elster and Geitel (Wied. Ann. 38, p. 498) were also unable to obtain any action with the substances used by Hoor.

† C. R. 109, p. 219. Beibl. 13, 976.

‡ Wied. Ann. 38, p. 40. Phil. Mag. 28, p. 427. (Abst.)

§ Meteorologische Zeitsch. 5, pp. 297 and 348. Beibl. 13, 328.

|| Wied. Ann. 38, p. 497.

face of the dish, and only a few millimeters distant, was placed a grounded piece of wire gauze, which served to protect the dish from the influence of the atmospheric electricity. With this apparatus a marked effect could be observed both with direct and diffused sunlight. Wires of Zn, Mg, or Al carefully cleaned and attached to an Exner electroscope were found to give a simple and sensitive portable apparatus.

75. Elster and Geitel appear to have been at first interested in the phenomenon chiefly on account of its important bearing upon meteorology, atmospheric electricity, etc. Much has in fact been written on this phase of the subject, which can only be mentioned here. They were anxious to obtain some instrument by which the actinic intensity of sunlight could be measured from hour to hour and day by day. Since the effect is influenced so greatly by slight changes in the character of the sensitive surface, it was difficult to find any active substance which would remain permanent. *Amalgamated zinc* was however found to fulfill the requirements, being much more permanent than pure zinc, and also more sensitive.

76. Elster and Geitel called attention to the fact that only *electro-positive* metals appear to possess 'actino-electric' sensitiveness.* It seemed therefore natural to expect that metals that are even more positive than Zn, Al and Mg, should show the effect in more marked degree. K and Na were tested, but, on account of the rapid oxydation of the surface, no action could be observed. The same trouble was met with in the case of solid amalgams of K and Na. By using a dilute solution of K or Na in mercury, and allowing the liquid to flow continuously from an aperture, a clean surface could however be maintained, and under these circumstances the effect of light upon a negative charge was very marked. With positive electricity there was no action. Pure mercury was entirely inactive.

77. The most sensitive metals as regards the action of sunlight were, in the order of sensitiveness:

K, Na, Al, Zn, Sn.

This series is exactly the same as the Volta contact series.

78. Sunlight produced no effect on unamalgamated but clean surfaces of

Sn, Cd, Pb, Cu, Brass, Fe, C, Pt.

79. From a meteorological standpoint experiments with surfaces of water appear of considerable interest. The zinc dish described above was therefore filled (1) with pure rain water; (2) with hot water (rapidly evaporating); (3) with salt water. No action could be detected from sunlight in any case. If any action exists it must be hundreds of times smaller than that observed with zinc.

80. In the course of these experiments Elster and Geitel obtained a noticeable effect with a powder used in making luminous paint (Balmain's Leuchtfarbe).

81. The action in the case of sunlight seems to depend upon somewhat longer waves than those of the extreme ultra-violet. Glass and mica, for example, do not stop the effect completely.

82. Elster and Geitel describe, at the close of their article, convenient forms of apparatus for showing the fundamental phenomena.* Lecture experiments are also suggested by Hallwachs.†

83. A method of conveniently using the highly sensitive sodium amalgam without deterioration of its surface was devised soon after by Elster and Geitel.‡ The amalgam was prepared and kept in a vacuum

*See § 34.

* An improved form of apparatus for this purpose is described in Wied. Ann. 42, p. 564.

† Wied. Ann. 41, p. 161.

‡ Wied. Ann. 41, p. 161.

tube, the pressure being in the neighborhood of 1 mm. Under these conditions the surface remained permanently unaltered. Such an active electric cell was extremely sensitive. Diffuse light was effective even through the glass sides of the tube; no quartz window or similar arrangement was at all necessary. The surface is sensitive even to rather long waves, for a slight effect was observed with the sodium flame.

84. In 1891 Elster and Geitel* again took up the investigation of the actino-electric behavior of sodium and potassium. Instead of amalgams, the clean unoxydized surfaces of the metals themselves were used. Such surfaces were prepared in vacuo by a method described at length in the article cited. The apparatus and connections are shown diagrammatically in Fig. 2. The metal, M, was kept perma-

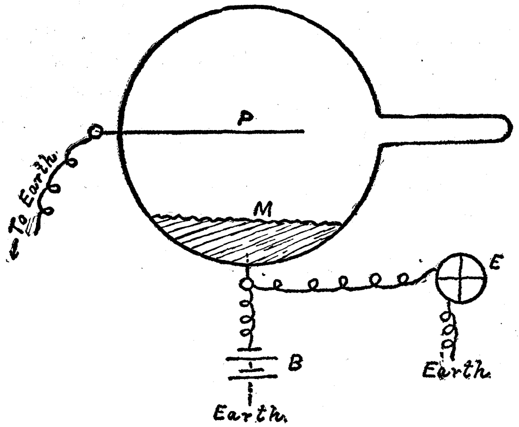

FIG. 2.

nently connected with the negative pole of a 'Zamboni' battery, B (a dry battery. See Wied. Elect. I.: 272), the positive pole of the battery being grounded. The potential of the negative pole was then measured by an Exner electroscope. (E in figure.) A platinum electrode, P, above the surface of the metal was kept grounded and served to carry away the charge dissipated from M.

* Wied. Ann. 43, p. 225.

85. Surfaces of pure potassium were found excessively sensitive. It was impossible to maintain a negative charge at all in a room lighted by daylight. An oil lamp 10 cm. distance reduced the potential from 212 volts to zero. Even at a distance of 6 m. its effect was noticeable. Magnesium light at the latter distance reduced the potential 60%. Even the rays from a Bunsen burner were effective, as was also the fluorescent light from luminous paint. A noticeable effect was observed with moonlight.

86. The effect of various absorbing media was next studied. Finally, the apparatus was placed in the solar spectrum formed by a glass prism. The maximum effect was found in the blue, but the influence was noticeable as far as the red, and far into the ultra-violet. It is suggested that this apparatus may be used to advantage in showing (for lecture experiments) the existence of rays beyond the violet.

87. On charging the potassium positively Elster and Geitel in some cases observed what appeared to be an increased rate of dissipation of *positive* electricity.* They show conclusively, however, that this result is due to the action of diffuse rays upon the (now) negative platinum electrode, P (see Fig. 2), and are strongly of the opinion that other observers who have published accounts of an action on positive charges have been misled by some similar disturbance.

88. Pure sodium surfaces were found somewhat less active than potassium. Experiments upon various amalgams gave results showing that the order of sensitiveness is as follows: Rb, K, Na, Li, Mg, Tl, Zn. Pure K and Na are more sensitive than any of the amalgams.

89. After a number of papers dealing with atmospheric electricity and the meteorological aspect of the negative discharge phenomena, Elster and Geitel again took

* l. c., p. 236.

up their study of the alkali metals in 1894.* Cells containing metallic Na, K and Rb were prepared by methods described in earlier papers.† An atmosphere of hydrogen was used in each case, the pressure being reduced to such a value (about $\frac{1}{2}$ to $\frac{1}{3}$ mm.) as would make the apparatus most sensitive. All measurements were made with a galvanometer, current passing between the illuminated surface and a ring of wire placed just in front of it.

90. Rubidium was found much more sensitive than either Na or K. The maximum effect was also further toward the red than in the case of Na and K, as shown by experiments with various absorbing solutions. For Rb the maximum was in the yellow, with a very noticeable effect in the orange and red. With both Na and K the maximum action was in the blue.

91. Elster and Geitel draw the conclusion that "not only does the actino-electric sensitiveness increase with the electro-positive character of the metal, but the electro-positive metals also show an increased tendency to be affected by light of greater wavelength."

92. In this same article‡ observations are also described showing the effect of illumination in helping the development of Hertz vibrations in vacuum tubes. The effect is especially marked when one of the alkali metals is present. These observations are intimately connected with work by Zehnder, Warburg and others on the behavior of Geissler tubes containing sodium. To follow out the matter in detail would require the considerable literature of this subject to be consulted. I shall therefore merely state the conclusion reached, viz: that in the presence of one of the alkali metals the effect of illumination is to render the gas capable of conducting the rapidly oscillating currents from a Hertzian oscillator.* Taken in connection with Arrhenius' discovery that rarified gases conduct electrolytically when illuminated,† this result has an important bearing upon J. J. Thomson's suggested explanation of actino-electric phenomena.‡

*Wied. Ann. 52, p. 433.

†A special mode of procedure was necessary in the case of Rb.

‡ l. c., p. 445.

BEHAVIOR OF FLUORESCENT MINERALS.

93. The theory advanced by Arrhenius, by which many phenomena of atmospheric electricity are explained as a result of the action of sunlight in discharging negative electricity from the earth's surface, seems to require that other substances besides the metals should be acted upon. A number of minerals, woods, etc., were therefore tested by Lampa,§ with negative results. Preliminary experiments by Elster & Geitel|| also failed to show any action of sunlight upon such substances. The sensitiveness of one non-metallic substance (Balmain's luminous paint) had however already been proved.¶ This substance being phosphorescent, it seemed not improbable that other phosphorescent materials would show the effect. Later experiments by Elster and Geitel** confirm this view. Various artificial phosporescent powders (*e. g.*, the sulphides of Ca, Sr, etc.) were found to show greater or less actino-electric sensitiveness, according as they were more or less strongly phosphorescent.

94. To observe the action of sunlight upon phosphorescing minerals, more sensitive apparatus was needed than that previously used. The arrangement of apparatus is shown in the figure. A dish, D, of oxydized iron was enclosed in a grounded

* See Wied. Ann. 52, p. 454.

† Wied. Ann. 32, p. 545; 33, p. 638.

‡ See § § 112, 113, below.

§ Wiener Anz. 1890. Beibl. 15, 384.

|| Wiener Berichte 99, p. 1008.

¶ Wied Ann. 38, p. 507.

** Wied Ann. 44, p. 722.

metal case, S, with an insulated wire leading outside to an electrometer. Just above D was a sheet of iron wire gauze, G. The substance to be tested was placed in the dish, D (in powder form), and the gauze, G,

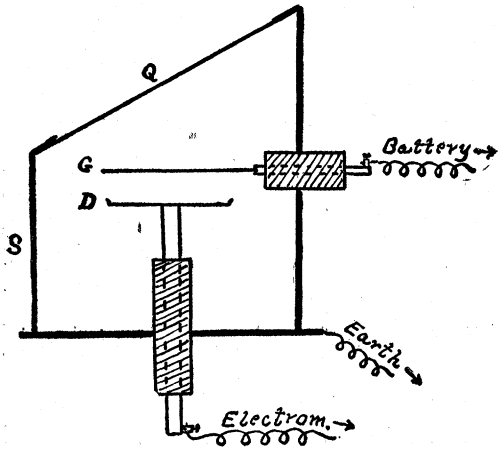

FIG. 3.

was kept at a positive potential of 300 volts. The quartz window, Q, being covered by a metal plate, D was grounded for an instant. The ground was then broken and light allowed to shine upon D. As the induced negative charge was dissipated, the electrometer showed an increasing deflection. This arrangement was found much more sensitive than that used before.

95. Among the minerals tested, certain varieties of fluorescing fluorspar were found most sensitive. The most effective rays were not the ultra-violet, but the blue. The sensitiveness of fluorite was not increased by diminished air pressure; and was not destroyed by wetting the surface with water.

96. Fluorite was rendered insensitive by being heated to redness; and its power of phosphorescing was also destroyed by this means. Elster and Geitel suggest that the phosphorescence and actino-electric activity are due to the presence of some organic impurity which is removed by heating.

Various other materials were tested and found to be slightly sensitive. Freshly fractured surfaces were more active than old surfaces.

EFFECT OF A MAGNETIC FIELD ON ACTINO-ELECTRIC PHENOMENA.

97. In the course of his low pressure experiments in 1890,* Righi found that the positive charge acquired under the influence of illumination is lessened when a magnet is so placed as to make the lines of force parallel to the surface. The particles which carry the charge 'appear to meet with opposition in their motion through the magnetic field, so that the actino-electric action is weakened.'

98. The influence of the magnetic field in diminishing the effect of illumination was discovered independently by Elster and Geitel,† who were led to investigate the matter through a consideration of somewhat similar effects in the case of the spontaneous discharge between incandescent and cooler bodies.‡ Amalgamated zinc was used as the active metal and the spark of an induction coil as a source of light. At pressures below 5 mm. the influence of illumination could be in some cases entirely destroyed by a magnetic field. In place of air H, CO_2, and O were also tried. CO_2 was found especially sensitive, both to the actino-electric effect and to the restraining influence of the magnetic field, but much lower pressures were necessary to exhibit the latter action. (Maximum at .005 mm.) These experiments were successfully repeated with daylight, sodium amalgam being used instead of zinc.

99. At the close of the article just cited § Elster and Geitel discuss at some length the probable cause of the phenomena. While accepting some form of convection as the

* Acc. dei Lincei 6, p. 81. Acc. di Bologna 10, p. 85. Beibl. 14, p. 1167.

† Wied. Ann. 41, p. 166. 1890.

‡ Wied. Ann. 37, p. 315; 38, p. 27.

§ l.c., p. 174.

method by which the negative charge is dissipated, they are inclined to adopt Righi's original view that the air particles act as carriers for the electricity. Against the explanation of Lenard and Wolf (particles of the body itself carrying charge) they urge the objection that charged dust particles will not be acted on by a magnetic field. (Why not, if in motion?) Elster and Geitel do not believe in the action of the condensed layer of gas (Hoor), but think that by a sort of resonance the ultra-violet rays make it easier for the gas particles in the neighborhood of the surface to receive a charge.

LATER INVESTIGATIONS OF ELSTER AND GEITEL. ACTINO-ELECTRIC EFFECT OF POLARIZED LIGHT.

100. Further actino-electric investigations by Elster and Geitel appear in Wiedemann's Annalen in 1892.* The authors point out that the behavior of an illuminated cathode is similar in many respects to that of an incandescent cathode.† If the analogy holds true, the resistance of a Geissler tube should be diminished by illumination of the cathode, as it is by heating the latter. The observations of Wiedemann and Ebert, however, contradicted this conclusion for low pressures.‡ Elster and Geitel therefore repeat these observations, using potassium as a cathode in a tube filled with hydrogen. Illumination of the potassium surface was found very noticeably to diminish the resistance (as shown by using an adjustable spark gap in air, in parallel with the tube). The effect was most marked at low pressures (0.1 mm. to 0.01 mm).

101. This same tube was then used to study the action of a magnetic field upon the actino-electric current. It was found that when the lines of force of the field were perpendicular to the direction of the convection current, the action in restraining the discharge produced by light was greatest. If the lines of force were parallel to the current, the action was either *nil* or else slightly reversed. In these investigations Elster and Geitel found it possible to measure the actino-electric current with a galvanometer, instead of using an electrometer.

102. In 1894 observations were made by Elster and Geitel * upon the actino-electric action of polarized light. Wanka † had already tried to detect a difference in the discharging action of light depending upon the direction of the plane of polarization, but without success. The difficulty seems to have been partly in the character of the surface and partly in the fact that completely polarized ultra-violet rays are not readily obtained. Elster and Geitel avoided the last difficulty by using cells of Na and K, which were sensitive to visible rays. A smooth and approximately plane surface was obtained by using the metals in liquid form. The light used was polarized by means of a nicol.

103. At oblique incidences the actino-electric effect was greatest when the vibrations of the incident light took place in a plane perpendicular to the sensitive surface, (Fresnel's Hypothesis), and least when the vibrations were parallel to the surface. The difference between the maximum and minimum was a function of the angle of incidence, and was found to be greatest for an incidence of about 60°.

104. In a later article‡ Elster and Geitel describe still further experiments on the action of polarized light. Keeping the

* Wied. Ann. 46, p. 281.

† The discharge from incandescent metal surfaces has been investigated by Elster and Geitel and others at considerable length. Most of the work on this subject will be found in Wiedemann's Annalen.—E. M.

‡ Wied. Ann. 35, p. 217.

* Berliner Akad. 6, p. 133. Wied. Ann. 52, p. 440. Abstracted in Phil. Mag. 38, p. 158.

† Mitth. d. Math. Gesellschaft in Prag., p. 63, 1892.

‡ Wied. Ann. 55, p. 684, 1895.

angle of incidence constant they investigated the change in the actino-electric current as the polarizing nicol was rotated. Attempts were made to use a cell containing a plane-parallel quartz window, but no cement could be found which would hold and yet not alter chemically the sensitive surface. Cells could, however, be constructed which would remain tight for a short time, and served to check the results obtained with spherical glass cells. In using the latter cells precautions were taken to have the rays from the zircon lamp pass normally through the glass. Only the central portion of the liquid metal surface was used.

105. Indicating the angle through which the nicol was turned from the position of maximum action by x, the actino-electric current was found to be given by the equation:

$$I = A \cos^2 x + B \sin^2 x.$$

This formula agrees with the assumption that the actino-electric effect is proportional to the incident light, but that the proportionality factor is different for light polarized in the plane of incidence and perpendicular thereto.

106. Observations were made at several different angles of incidence (70°, 66°, 40°, 23°). The ratio of A to B was found to depend upon the angle of incidence. Both A and B were small for normal incidence. A increases to a maximum at an incidence of about 60°, and then decreases. B appears to decrease steadily to practically zero at grazing incidence. At 60° the ratio of B to A was found to be 50.

107. Good effects with polarized rays could only be obtained with the smooth, nearly plane surface of liquid K or Na. Solid Na or K always show rather a rough surface and behave in practically the same manner for polarized and unpolarized light.

108. Experiments were tried with amalgamated zinc at ordinary pressures, but here, too, the behavior with polarized rays was scarcely different from that with unpolarized light. The authors think that this is due to the difficulty of obtaining ultra-violet rays completely polarized.

EFFECT OF LIGHT UPON POSITIVELY CHARGED BODIES.

109. When the attempt is made to find a satisfactory explanation of the action of light upon charged bodies, the fact that the action seems to be confined to *negative* charges is of great significance. Several observers have, indeed, found indications of a discharging action in the case of positively charged bodies. Mention has already been made of such indications in the case of the experiments of Hallwachs, Righi, and Elster and Geitel. But these observers were able to show that the apparent dissipation of a positive charge under the influence of ultra-violet rays was in reality a secondary phenomenon, due to the convective discharge from negative bodies in the neighborhood. They were of the opinion that the action of light upon a positive charge, if such action exists at all, is too small to be measured.

110. In contradiction to these conclusions stand the results of numerous experiments by Branly.* Under circumstances where previous observers had found no trace of any action, Branly detected a very rapid dissipation of positive electricity. The lack of a detailed description of the experiments leading to these results makes it impossible to draw any conclusion in regard to their reliability. But the question is of such importance that Elster and Geitel† have recently undertaken a series of experiments intended either to confirm or dis-

*C. R. 110, p. 751, 1890; 110, p. 898; 114, p. 68, 1892; 116, p. 741, 1893; Lumière elect. 41, p. 143, 1891; Jour. de Phys. 2, p. 300, 1893; Abstracts in the Beiblätter.

†Wied. Ann. 57, p. 24, 1896.

prove Branly's conclusions. The experiments of the latter were repeated as nearly as possible under the original conditions, and indications of a loss of positive electricity were in fact found. But it was in all cases possible to ascribe these results to disturbances, as in Elster and Geitel's previous experiments. And when the experiments were modified so as to more completely remove the sources of disturbance, the apparent loss of positive electricity became insignificant. In view of the fact that the X-rays, whose discharging action is in many respects similar to that of ultraviolet light, are capable of dissipating *both* charges, it seems probable that some effect is also produced by light upon a positive charge. The experiments of Elster and Geitel indicate, however, that this action must be extremely small.

THEORIES PROPOSED.

111. Although it has been shown, I think conclusively, that the dissipation of a negative charge by light is accomplished by convection, the theories heretofore cited do not explain how this convection is brought about; and they also leave unexplained the still more important fact that negative charges only are affected. The theories proposed by J. J. Thomson* and by Elster and Geitel† respectively seem satisfactory, however, in regard to both these difficulties.

112. Thomson bases his explanation of the phenomenon upon the hypothesis of Helmholtz that "bodies attract electricity with different degrees of intensity." This conception was shown by Helmholtz to be able to explain electrification by friction and the differences of potential produced by contact. If the attraction of a metal for positive electricity is greater than that of the dielectric surrounding it, the tendency is for the metal to become positively charged.

* Recent Researches in Elect. and Mag., p. 64.

† W. A. 55, p. 697.

But "when a conductor, which does not disintegrate, is surrounded by air in its normal state, * * * the conductor cannot get charged * * * for the electricity of opposite sign to that which would be left on the conductor has no place to which it can go." "The case is, however, different when the conductor is exposed to the action of ultra-violet light, for then, as Lenard and Wolf's experiments prove, one or both of the following effects must take place: (1) disintegration of the conductor; (2) chemical changes in the gas in the neighborhood of the conductor which put the gas in a state in which it can receive a charge."

113. The first effect mentioned, namely, disintegration of the metal, might be produced by the absorption of the light rays, as explained in § 71. On the other hand, it is quite conceivable that light, and especially the ultra-violet rays, may produce electrolytic dissociation in the gas, and so render the latter capable of taking a charge. This hypothesis is strengthened by the experiments of Arrhenius,* who found that certain gases became conductors when illuminated. That some such change in gases is produced by X-rays is now proven beyond question.

114. The theory suggested by Elster and Geitel depends upon the assumption that the electro-positive character of the metal relatively to the dielectric causes the formation of two charges, viz: A positive charge on the metal, and an equal negative charge in the adjacent portions of the gas. These two charges being extremely close together, their outside effect disappears. When light waves fall upon the surface in such a manner as to give a component electric displacement (electro-magnetic theory) in the direction of the normal, electric oscillations will be set up in the metal. These oscillations may be sufficiently powerful to destroy

* Wied. Ann. 32, p. 545; 33, p. 638; Phil. Mag. 28, p. 75.

at times the positive surface charge, or even to reverse it. The negatively charged particles of the gas will thus be driven away, while others will come to take their places, and in so doing will impart additional positive electricity to the metal. The fact that strongly electro-negative gases, such as H and CO_2, give an especially marked photo-electric action seems to support this view. On the other hand, as is pointed out by Elster and Geitel, this explanation seems to require that all action should cease when the light rays fall normally on the surface, a conclusion which is not borne out by experiment.

CONCLUSION.

It is clear from what precedes that a thoroughly satisfactory explanation of the discharging action of light has not yet been found, and that many questions concerning the phenomenon remain to be settled by further experimental investigation. That interest in the subject is not diminishing is evidenced by the number of papers that have only recently been published. A list is given below of those that have come to my attention too late to enable their results to be included in this article.

Elster and Geitel. The influence of light on the form of the discharge from a Holtz machine. Wied. Ann. 57, p. 401, 1896.

Elster and Geitel. On a photo-electric after effect of cathode rays. Wied. Ann. 59, p. 417. 1896.

Warburg. The action of light on the spark discharge. Wied. Ann. 59, p. 1. 1896.

Klemencic. A lecture experiment to illustrate the mutual influence of two spark gaps. Wied. Ann. 59, p. 63.

Swyngedauw. Action of ultra-violet light upon explosive, static and dynamic potentials. C. R. 122, p. 131, 1896. Beibl. 20, 660.

Dufour, Dutoit and *Hofer.* Dissipation of electricity under the action of light. Arch. de Genéve, 34, p. 294, 1895.

Simon. On the influence of waves of high refrangibility upon the electrical conductivity of rarified gases. Wiener Berichte, 104, p. 565, 1895.

Batelli and *Garbasso.* On the dissipation of electrostatic charges by ultra-violet rays. Nuovo Cimento III., p. 321, 1896.

Sella and *Maiorana.* Action of Röntgen raysand of ultra-violet light on the disruptive discharges in air. Nuovo Cimento III., p. 238, 1896.

The bearing of the phenomena here described upon the question of the nature of the X-rays is doubtless of especial interest at the present time. The fact that the X-rays are capable of producing a rapid dissipation of electricity from charged bodies has been urged in support of the view that these rays are similar in kind to ultra-violet light, but of excessively small wave-length. The argument loses some of its force when we recall the fact that ultra-violet rays are capable of dissipating a *negative* charge only, while the action of the X-rays is practically the same for both charges. This difference between the two phenomena does not in itself offer a fatal objection to the argument, but recent experiments of Batelli and Garbasso (see above reference) indicate a much more fundamental differerence between the two effects. It has been found that air which has been exposed to X-rays retains the power of discharging electrified bodies even when no longer exposed to those rays. No indication of such an after effect has been found in the case of ultra-violet light. The work of Batelli and Garbasso was undertaken with the special object of testing this point, and their results show that no trace of an after effect can be detected with the rays from an arc lamp, even when the direct discharging action is as great as that produced by X-rays. If these results are confirmed I think we shall be forced to the conclusion that the discharging action of ultra-violet light differs essentially from the similar effect produced by the Röntgen rays.

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